Usefulness of chest images for the assessment of pectus excavatum before and after a Nuss repair in adults

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Keywords: Pectus excavatum • Chest radiograph • Nuss procedure • Adult • Minimally invasive procedure • Haller index

INTRODUCTION

Pectus excavatum (PE) is the most common congenital chest wall deformity and is usually recognized in infancy. The condition occurs in one of every 800–1000 live births, with a male predominance [1, 2]. PE is characterized by a caved-in deformity of the sternum and lower costal cartilages, resulting in a diminished anterior–posterior (AP) distance of the thoracic cage [3]. The deformity may become more pronounced during the pubertal growth spurt and individuals may experience worsening symptoms after adolescence if the PE is not repaired [4–6].

Surgical correction is still considered the standard treatment for PE, and may be performed using an open method (the Ravitch procedure) or using a minimally invasive technique. The minimally invasive repair of PE described by Nuss et al. [1] in 1998 has been used extensively in the recent decade [5–10]. The procedure was initially preferred in children and young adolescents [1, 7]. After the modification of this procedure and the accumulation of clinical experience, recent reports have demonstrated that it can also achieve good results in adult patients [5–8]. However, no objective methods for monitoring the anatomical results of a Nuss repair have been demonstrated in adults, especially after the removal of the bar(s).

Many radiological scales are used to quantify the severity of the anatomical deformity in PE preoperatively, such as the Haller index (HI) [11], sternovertebral distance (SV) [12] and cardiac compression index [13] calculated from many kinds of radiological modalities including anteroposterior and lateral chest radiography (CXR) and chest computed tomography (CT). Among these scales, the HI calculated from CT has been used most often, but at the cost of high-radiation exposure and high medical expense [3, 14–16].
Several reports have demonstrated structural changes after the Nuss repair procedure for PE in young patients [14–17], but not in adults. The purpose of this study was to evaluate whether the dimensions or indices measured on a CXR could provide useful information for pre- and postoperative assessment and the follow-up after removal of the bars after the Nuss procedure in adults with PE.

PATIENTS AND METHODS

We retrospectively reviewed the medical records of all adult patients (aged ≥18 years) with PE corrected by a Nuss repair at the Division of Thoracic Surgery, Tri-Service General Hospital, Taipei, Taiwan, between April 2005 and December 2009. Posterior-anterior (PA) and lateral (Lat) CXR and chest CT (with 5-mm-thick sections) were performed in all patients before the operation. The indications for surgical repair were two or more of the following criteria, as originally described by Nuss: (i) progression of the deformity; (ii) exercise intolerance; (iii) progressive chest pain or dyspnoea; (iv) restrictive ventilatory impairment; (v) HI >3.25 (ratio of the transverse thoracic dimension to the SV at the most depressed point, as detected on CT of the chest) [11]; (vi) cardiac compression and (vii) mitral valve prolapse [7, 18].

The surgical procedure was conducted using video-thoracoscopy-assisted Nuss repair, as described previously [8]. In brief, one small vertical skin incision was made in the midaxillary line on each side. After the subcutaneous or submucosal dissections were performed, the pleural cavities were entered at the highest point of the funnel. First, a right thoracoscopy with a 5 or 10 mm 0° scope was performed, entering the pleural cavity via the right surgical wound for the direct inspection of the mediastinal structures. A left thoracoscopy was later performed via the left surgical wound. A right-to-left mediastinal dissection was performed with an introducer under a direct left thoracoscopic visualization. After a substernal tunnel was produced, a 28 Fr chest tube was connected to the introducer and retained in the thorax after the introducer was pulled back. A pre-bent Lorenz pectus bar (Lorenz Surgical, Jacksonville, FL, USA) was connected to the chest tube and advanced across the mediastinum. After the pectus bar was rotated and anchored into position, the bar was fixed with either a 1.0-mm stainless steel wire or heavy non-absorbent sutures at the end holes of the pectus bar and the right hinge point. In patients with very long and severe forms of PE, an additional substernal tunnel was made under the direct left thoracoscopic view and another pectus bar was introduced and fixed. The bar was removed at least 3 years after the repair was performed.

This study was approved by the Ethics Committee and the Institutional Review Board of the Tri-Service General Hospital, National Defense Medical Center, Taipei, Taiwan, ROC (TSGH-IRB no: 098-05-244). Postoperative PA and Lat CXR were performed as radiological follow-up at 1, 3, 6 and 12 months after the operation. A radiological evaluation was also performed after 1 month and then every 6 months after the removal of the bar. The HI and SV parameters were assessed during follow-up and to evaluate the results of the Nuss repair. On CXR, the SV was measured at the point of the most-posterior projection of the sternum on the Lat view. The transverse diameter was measured on the PA view at the same vertebral level as the SV measurement was made on the Lat view (Fig. 1). These radiological parameters on CXR and CT were independently detected and calculated by a radiologist (H.-H.H.) and a thoracic surgeon (T.-H.W). The HIs calculated using preoperative CT and CXR and postoperative CXR were compared. The SV on Lat CXR was also analyzed. The interval changes before and after the removal of the bar(s) were also compared.

The statistical analyses were performed with SPSS software (version 12.0; SPSS, Chicago, IL, USA). The descriptive data are expressed as means and ranges. Student’s t-test was used to compare the values. The $\chi^2$ test was used to compare categorical variables between groups. The Pearson correlation score was used for rank correlations. A P-value < 0.05 was considered statistically significant.

RESULTS

A total of 154 patients (131 men and 23 women) with a mean age of 24.0 ± 5.0 years (range, 18–44 years) were enrolled in this study. Sixty-two of these patients underwent bar removal during the follow-up period. The demographic features and clinical characteristics of the patients are shown in Table 1.

The preoperative mean HIs on chest CT scans and the CXR were 4.61 ± 1.58 (range, 2.6–11.9) and 3.82 ± 1.17 (range, 2.0–10.2), respectively, with a correlation coefficient of 0.757 (Fig. 2). This indicates a good correlation between the preoperative mean HIs measured with these two chest imaging modalities. An HI value of 3.25 calculated from a CT scan was correlated with an HI value of 2.5 calculated from the CXR.

The postoperative mean HI on the CXR was 2.86 ± 0.56 (range, 1.7–5.4), showing significant improvement when compared with the preoperative HI (P < 0.001; Table 2). The mean improvement in the HI was 0.96 ± 0.84 (22.9 ± 11.0%, P < 0.001). The mean SV values detected on preoperative and postoperative Lat CXR were 7.67 ± 1.89 cm (range, 2.5–12.9 cm) and 9.89 ± 1.80 cm (range, 4.6–15.0 cm), respectively. The mean increase in the SV was 2.22 ± 1.05 cm or 33.1 ± 25.7% (P < 0.001), thereby showing significant improvement.

The mean SV was 9.25 ± 2.14 cm in patients after the bar removal, also showing a significant improvement compared with the preoperative SV (mean increase in the SV was 1.58 ± 1.12 cm or 21.3 ± 18.7%, P < 0.01). However, there was no significant difference between the SV values before and after the bar removal (P = 0.2).

DISCUSSION

Although the Ravitch repair was commonly used in adults during the early decades of surgical intervention for PE [19, 20], there has been an increasing tendency towards the use of a minimally invasive approach for its correction in adults [5, 6, 8–10]. The minimally invasive repair of PE in children and adolescents was first introduced by Nuss et al. [1] in 1998. The method was primarily designed for prepubertal children, and the recommended optimal age was 6–12 years. Initially, the procedure was considered inappropriate for adult patients, because the adult chest is less flexible and less pliant than a child’s chest because of ossification with increasing maturity, and there is a greater risk of complications with the Nuss procedure in adult patients [21, 22].

CT is the most commonly used method of assessment. However, because CT only allows the calculation of the HI, some
authors have suggested that the PA and Lat CXR can replace CT [14, 15], but the samples studied have been limited to adolescents or children. There is also a lack of objective quantitative assessment of chest improvement after the Nuss procedure. Nakagawa et al. [16] described using the chest CT to evaluate the postoperative results; however, because the bar appears as an artefact on CT, CT can only be used after the bar removal. Kilda et al. [17] reported the use of PA and Lat CXR to evaluate the postoperative results of the Nuss procedure, but they also limited their analysis to children and did not correlate the CT and CXR data.

In our series, we demonstrated that HIs calculated from preoperative CXR correlate significantly with those calculated from the chest CT, demonstrating that the CXR can replace CT for the calculation of the HI. This can reduce the patient’s exposure to radiation and minimize costs. Our results are consistent with those of Mueller et al. [14] and Khanna et al. [15] in a population of children and adolescents, which we have extended to an adult population. To our knowledge, our study is the first to compare HIs measured on CXR and CT in an adult population. According to the correlation curve of HIs measured using CT and a CXR, an HI value of 3.25 calculated using CT correlates to

Figure 1: (A) Demonstration of the measurement of indices using CT. The maximum transverse chest diameter (a) is divided by the most-posterior sternal compression SV distance (b). (B and C) Demonstration of the measurement of indices from CXR before the Nuss operation. The point of the most-posterior projection of the sternum is identified, and the SV distance (b) is measured. The transverse diameter (a) is measured on the antero-posterior view at the same vertebral level as on the lateral view. (D) Demonstration of the SV distance measurement from the CXR after the Nuss operation. The point of the most posterior projection of the sternum is identified, and the SV distance (b) is measured. (E) Demonstration of the SV distance measurement on the CXR after the bar removal. The point of the most posterior projection of the sternum is identified, and the SV distance (b) is measured.
An HI value of 2.5 calculated from the CXR. An HI value >3.25 calculated using CT indicates severe chest depression, which is an indication for surgical correction, and an HI value >2.5 calculated from a CXR can be used as the reference value to define the indication for surgery.

The results of the Nuss procedure can be usually described in terms of the subjective cosmetic appearance as excellent, good, fair or unsatisfactory. Limited reports of the use of CT or a CXR in the quantitative assessment of children and adolescents are found in the literature [11, 16, 17]. To our knowledge, there are no reports of the quantitative assessment of the results of the Nuss procedure using radiological parameters in the adult population. In our study, the postoperative mean HI measured from a CXR demonstrated a significant improvement compared with the preoperative HI. In the report of Nakagawa et al. [16], the mean HI of the normal population measured by CT was 2.47 (range, 1.92–3.70), which is consistent with our postoperative mean HI measured from the CXR (2.86 ± 0.56). This indicates that the HI measured from the CXR can be used for the objective quantitative assessment of the results of the Nuss repair, and that the Nuss procedure can appreciably elevate the sternum into the normal range.

In addition to the HIs calculated from the PA and Lat CXR, we measured the SV from the Lat CXR. Like the HI, the SV measured from the Lat CXR showed significant improvement after the Nuss operation. This also demonstrated the remarkable elevation of the sternum achieved with the Nuss procedure. Some authors have argued that the simple SV does not accommodate the patient’s age and size in defining the severity of the malformation, and have used the vertebral index instead, which is the percentage ratio of the vertebral body length to the sum of the SV and the vertebral length [23]. However, in the adult population, the patients have undergone their growth spurts and the vertebral body length is stable thereafter, and so the SV will show any improvement after the Nuss procedure in this population and can be used as a simple modality at follow-up.

In the subgroup of 62 patients who underwent the removal of the pectus bar, the SV showed a tendency to decrease by 0.80 ± 0.60 cm (8.17 ± 6.1%) compared with the SV before the bar removal, but the difference was not significant. This means that the results of the Nuss repair were maintained after the bar removal. This result was comparable with the low recurrence of PE after the bar removal in adults as reported by other authors [5, 24]. However, the number of patients in this subgroup was limited, and a long-term follow-up is required to confirm these results more precisely. Nevertheless, the SV after the removal of

### Table 1: Demographic variables and clinical characteristics of 154 patients with PE corrected with the Nuss procedure

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, years, mean (IQR)</td>
<td>24.0 (18–44)</td>
</tr>
<tr>
<td>Sex (M:F)</td>
<td>131:23</td>
</tr>
<tr>
<td>BMI, kg/m², mean ± SD</td>
<td>20.4 ± 2.6</td>
</tr>
<tr>
<td>Family history, n (%)</td>
<td>47 (30.5)</td>
</tr>
<tr>
<td>Scoliosis, n (%)</td>
<td>50 (32.5)</td>
</tr>
<tr>
<td>Another congenital anomaly, n (%)</td>
<td>2 (1.3)</td>
</tr>
<tr>
<td>Haller index on CT, mean (IQR)</td>
<td>4.61 (2.6–11.9)</td>
</tr>
<tr>
<td>Restrictive pulmonary function, n (%)</td>
<td>36 (23.4)</td>
</tr>
<tr>
<td>Mitral valve prolapse, n (%)</td>
<td>0 (0.0)</td>
</tr>
<tr>
<td>Operative time, min, mean (IQR)</td>
<td>69.5 (50–135)</td>
</tr>
<tr>
<td>Double bars placed, n (%)</td>
<td>56 (36.4)</td>
</tr>
<tr>
<td>Estimated blood loss, ml, mean (IQR)</td>
<td>13.5 (10-50)</td>
</tr>
<tr>
<td>Surgical complications*, n (%)</td>
<td>14 (9.1)</td>
</tr>
<tr>
<td>Mortality, n (%)</td>
<td>0 (0.0)</td>
</tr>
<tr>
<td>Length of stay, days, mean (IQR)</td>
<td>7.4 (4–17)</td>
</tr>
<tr>
<td>Patient follow-up, months, mean (IQR)</td>
<td>36.5 (16–64)</td>
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IQR: interquartile range.
*Surgical complications: occurrence within 30 days of the operation.

### Table 2: Haller index and SV distance measured on the CXR

<table>
<thead>
<tr>
<th></th>
<th>Pre-op</th>
<th>Post-op</th>
<th>Δ₁</th>
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<tr>
<td>HI</td>
<td>3.82 ± 1.17</td>
<td>2.86 ± 0.56*</td>
<td>0.96 ± 0.84*</td>
<td>22.9 ± 11.0%*</td>
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<td>0.80 ± 0.60*</td>
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<tr>
<td>SV (cm)</td>
<td>7.67 ± 1.89</td>
<td>9.89 ± 1.80*</td>
<td>2.22 ± 1.05*</td>
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Pre-op: before the Nuss operation; Post-op: after the Nuss operation; Post-rem: after bar removal; HI: Haller index; SV: sternovertebral distance.

Values are means ± SDs.
Δ₁: post-op minus pre-op; Δ%₁: Δ₁/pre-op; Δ₂: post-op minus post-rem; Δ%₂: Δ₂/post-op.
*P < 0.001 compared with pre-op HI.
†P < 0.001 compared with pre-op SV.
‡P = 0.2 compared with post-op SV.

Figure 2: Correlation between the Haller indices measured from the CXR (HI-CXR) and the Haller indices measured using CT (HI-CT). There was a strong correlation between the HI-CXR and the HI-CT. Pearson’s correlation coefficient was 0.757. A HI-CT value of 3.25 correlates to a HI-CXR value of 2.5.

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the bar demonstrated a significant improvement compared with
the preoperative value.

**CONCLUSION**

We have shown that the HI estimated from a two-view CXR cor-
relates statistically significantly with that estimated from CT. The
SV measured from a Lat CXR showed signi
ificant improvement after the Nuss procedure and bar removal compared with the
preoperative value. Therefore, the two-view CXR can be used as
a simple modality for the preoperative assessment of PE severity,
the quantitative assessment of the results of Nuss repair and
during the postoperative follow-up. No routine CT of the chest is
required.

**Conflict of interest:** none declared.

**REFERENCES**

[1] Nuss D, Kelly RE Jr, Croitoru DP, Katz ME. A 10-year review of a minim-
ally invasive technique for the correction of pectus excavatum. J Pediatr
112-year autopsy series: anatomic findings and the effect on survival. J
[3] Rattan AS, Laor T, Ryckman FC, Brody AS. Pectus excavatum imaging:
[4] Fonkalsrud EW, De Ugarte D, Choi E. Repair of pectus excavatum and
repair of pectus excavatum in adult patients. J Thorac Cardiovasc
improves the quality of life in young male adults with pectus excavatum
tion update for the minimally invasive Nuss procedure. J Pediatr Surg
[8] Cheng YL, Lee SC, Huang TW, Wu CT. Efficacy and safety of
modified bilateral thoracoscopy-assisted Nuss procedure in adult
patients with pectus excavatum. Eur J Cardiothorac Surg 2008;34:
1057–61.
repair of pectus excavatum: a novel morphology-tailored, patient-
[10] Krasopoulos G, Goldstraw P. Minimally invasive repair of pectus excava-
[12] Fabricius J, Davidsen HG, Hansen AT. Cardiac function in funnel chest;
twenty-six patients investigated by cardiac catheterization. Dan Med Bull
new cardiac deformity indexes for pectus excavatum on computed tom-
ography: feasibility for pre- and post-operative evaluation. Yonsei Med J
for preoperative imaging of pectus excavatum. J Pediatr Surg 2008;43:
71–3.
index values calculated with chest radiographs versus CT for pectus excava-
[16] Nakagawa Y, Uemura S, Nakaoka T, Yano T, Tanaka N. Evaluation of the
Nuss procedure using pre- and postoperative computed tomographic
Radiological changes after Nuss operation for pectus excavatum. Medica
(Caunas) 2009;45:699–705.
[18] Kelly RE Jr. Pectus excavatum: historical background, clinical picture, pre-
operative evaluation and criteria for operation. Semin Pediatr Surg 2008;
17:181–93.
Haller index values calculated with chest radiographs versus CT for pectus excava-
and discussion of the complications of minimally invasive pectus excava-
changes in chest wall compliance in infancy and early childhood. J Appl
ure: pediatric surgical solution for adults with pectus excavatum. World J